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THERMAL PERFORMANCE EVALUATION OF LITHIUM POLYMER BATTERIES: A COMPARISON OF PCM AND PCM WITH METAL FOAMS FOR THERMAL REGULATION

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1. ABSTRACT

This study focuses on addressing the thermal issues of rechargeable batteries in electric vehicles by isolating them from external climatic variations and regulating the increase of temperature during its operation. The thermal management of cylindrical lithium polymer-based battery cell module is numerically studied using a three-dimensional model, evaluating the different cooling passive mechanisms based on PCM and metal foams of different pore densities and porosities for two chosen C-rates of 0.5C and 1C respectively.

2. INTRODUCTION

Lithium-ion batteries are distinguished by their inherent properties such as low self-discharge, better performance in low temperatures, absence of memory effect and simple reliable charging methods. They are energy efficient, cost-effective and offer an excellent life cycle relative to other battery chemistries including lead-acid and nickel metal hydride [1]. Hence these batteries are highly preferred in electric vehicles. Moreover, Battery Thermal Management technique is quite essential to maintain and regulate the working conditions of the battery pack. This technique in turn helps in avoiding the phenomenon of thermal runaway. Different kinds of thermal management techniques are available so as to control and regulate the temperature of the modules.

3. METHDOLOGY

Physical Model:

A three-dimensional model is employed for the numerical analysis of thermal control in a cylindrical lithium manganese oxide battery module, measuring 65 mm in height and 18.4 mm in diameter, with a capacity of 3000 mAh. The module is placed in a parallelopiped structure surrounded by convective channels that allows liquid flow for cooling during the charging and discharging process. These tubes are maintained at a constant temperature of 293.15 K and the whole module is considered adiabatic as considered in the study of [2] The batteries are surrounded by phase change material (PCM) namely RT27 during the initial case and a mixture of metal foams with different pore densities and porosities (5, 40PPI and 0.946, 0.952) are embedded with the PCM during the second case so as to cool the batteries during the process of discharge. In Fig.1, the cylindrical batteries are highlighted in red, whereas the channels through which the liquid flows are represented in blue, and the remaining grey area signifies the mixture of phase change material with metal foams of different pore densities depending on the three chosen cases.

Although Figure 1(a) represents a complete battery pack, a single battery module is chosen for this study. The system being completely symmetrical in nature, a single module of the system was selected as shown in Figure 1(b)which in turn was reduced to a quarter as represented in Figure 1(c) which was further simulated.

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In the study proposed by [3], the space maintained between the two adjacent cells was 10mm. This reduces the computational cost as it involves a huge number of nodes as well as the results obtained will be reliable.

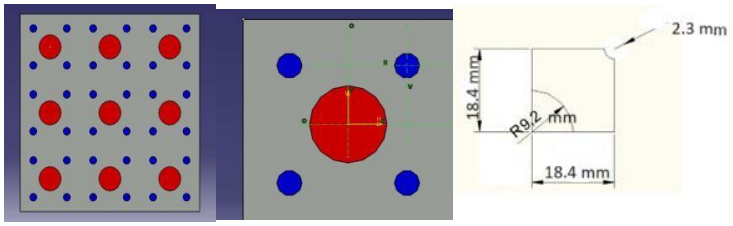

Fig.1 (a) Schematic diagram of battery pack with the various elements; (b) Single module of the battery cell; (c) Symmetrical division of the single module to a quarter dimension

Using the experimental analysis, the battery Efest:IMR18650 cell was chosen to be discharged for the two specific C-rates of 0.5 and 1C respectively. During the process, the temperature and the output voltage were determined for a constant current discharge. Further, the estimation of the variable thermal resistance was approximated for the discharge process using the depth of discharge as the reference parameter. The selection of non-linear exponential regression model as recommended by [4] was chosen for the estimation of the internal resistance. Utilizing the Generalized Gradient Algorithm, the estimation process employed the process of curve fitting as suggested in [5].

Mathematical Formulation of the Module

The various assumptions of the numerical model designed are illustrated below:

i). The thermophysical properties of the phase change materials were assumed to be constant throughout and the variation in volume is ignored. The initial temperature was assumed to be an ambient temperature.

ii). The metal foam was assumed to be homogeneous and isotropic during its operation. Radiation in heat transfer is neglected.

iii). The phase change material in the liquid phase will be subjected to Boussinesq's approximation. The liquid PCM is considered to be incompressible, isotropic Newtonian fluid.

The various fundamental physical governing equations of the numerical model are those as suggested in [2]. The numerical model is designed based on the principles of the Continuity equation as well as the momentum and the Energy equations. The melting and solidification of the PCM is modeled using the principle of Enthalpy- Porosity method. This method defines a mixed region of both solid and liquid which is described as a pseudo-porous zone, where the porosity equals the liquid fraction indicated using β. The value of liquid fraction tends between 0 and 1, the minimum being when the zone is completely solid and maximum being when the zone is completely liquid. The momentum dissipation terms are added appropriately which contributes to the pressure drop caused by the solid materials. Moreover, the heat transfer process is modelled based on the Local Thermal Equilibrium process (LTE), which assumes the temperature of the porous medium and the PCM to be at the same temperature. The momentum equations were governed by the various source terms involving the Kozeny-Carman term corresponding to the solid part of the phase change material, the permeability of the material involved the Darcy term and finally the inertial resistance described using the Forchheimer's coefficient.

The boundary conditions based on which the model is designed are the upper part of the module is assumed to be adiabatic and the interface between the module and the PCM is at the same temperature.

4. RESULTS

Based on the experimental results, the regression analysis was performed to estimate the internal resistance of the module during the process of discharge. The regression equations obtained are shown in Figure 2 regarding the two chosen C-rates.

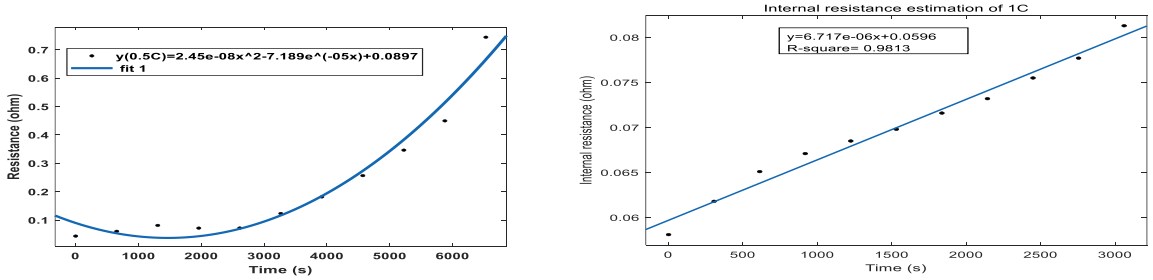

Fig.2 Regression analysis of the estimation of internal resistance for the two chosen C-rates of 0.5 and 1C

The numerical analysis was conducted using the Ansys-Fluent software. The average temperature acquired by the battery and the maximum surface temperature during the process of discharge for the two chosen C-rates were analyzed. The initial case being where the battery module is cooled only using the PCM, whereas in the second and third case, the battery is cooled using the PCM embedded with metal foams of two different pore densities of 5 and 40 PPI respectively. The Figure 3 describes the average temperature of both 0.5C and 1C respectively where the average temperature acquired by the battery was around 299 K and 300 K in case of using only PCM whereas the temperature decreased to around 294 K during the applications of the metal foams in both the cases. Similar was the case of the maximum surface temperatures acquired by the battery as illustrated in Figure 4. However, it is generally prescribed to choose metal foams of high pore densities and lower porosities so as to have an efficient process as suggested by [6].

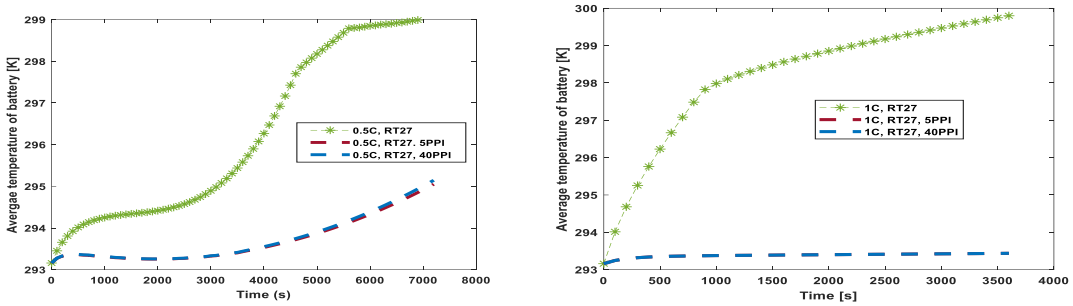

Fig.3 Average temperature acquired by the battery for two chosen C-rates

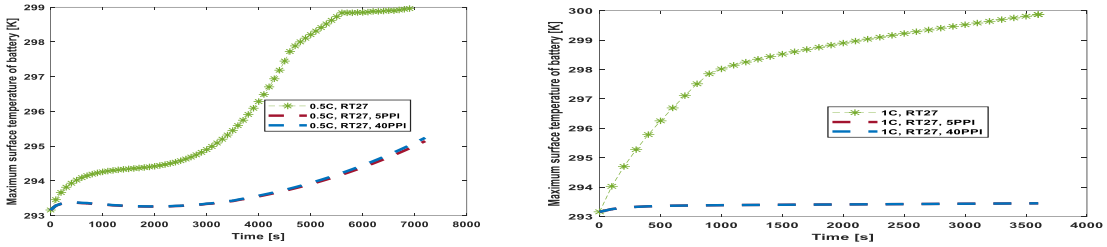

Fig.4 Maximum surface temperature acquired by the battery for two chosen C-rates

5. CONCLUSIONS

This study focused on the thermal analysis of lithium manganese oxide battery with respect to two C-rates namely 0.5 and 1C respectively. An experiment was conducted to analyze and estimate the change in thermal internal resistance by the principle of GRG algorithm using the concept of regression. Furthermore, a numerical model was proposed based on the principles of LTE system. The battery system was modelled based on three configurations using only PCM, and PCM embedded with metal foams of two different pore densities. From the analysis, it was observedthat the cooling mechanism involving the PCM with the mixture of metal foam performed much better than the case with pure PCM so as to cool the battery. Moreover, the two different pore densities did not show much difference in temperature in this study, since the porosities of the metal foams were almost in the same range.

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